RADCOM
TECHNICAL
FEATURE

HF/VHF Vee Beam Design & Performance

The first of two parts by Richard A Formato, PhD, K1POO*

I SUSPECT THERE are two reasons why Sloping Vees aren't everywhere:

1. you will probably have to design and build the antenna yourself.
2. really good designs take up quite a bit of space.

But for anyone who enjoys experimenting with antennas and has access to even a modest amount of space, the Vee is simply one of the best. This antenna provides a splendid combination of low cost, excellent gain-bandwidth product, electrical and mechanical simplicity, ease of design, construction and installation, and the bonus benefit of inherent polarisation diversity. Although the Vee is usually thought of as an HF antenna, it's useful from MF through UHF and should be considered as a candidate for most communication links.

This article is about the nuts and bolts of Sloping Vee performance and design. Its point of view is practical and system engineering oriented, not abstract or theoretical. All factors important in Vee design are considered, and design methodology is discussed. We will also look at specific antennas: some optimised for gain (how about 16.5dBi at 10MHz or 18dBi at 56MHz!); another providing coverage of the upper HF and lower VHF bands (10-60MHz); and a prototype design covering the HF band from 5-30MHz on a typical link from Sheffield (UK) to Chicago (USA).

ANTENNA GEOMETRY

A TYPICAL VEE INSTALLATION is shown in **Fig 1**. The antenna appears schematically in **Fig 2**, which is a perspective view (resistors R are both at the same height H_t). The Vee consists of two wire radiating elements terminated by equal value resistors. A shorting wire must connect the resistors to complete the current path. The feed point is located on top of a non-conducting mast at the vertex of the two radiating elements. Either a parallel-wire (balanced) or coaxial (unbalanced) feed line can be used. The coax feed is more common for amateur radio and SWL applications but it does require a balun. If a conducting mast is used, it is advisable to place the feed point at least one metre from the mast, and run the feeder horizontally from, the feedpoint to the mast.

The Vee's key design parameters are the radiating element length (L) and diameter (D), the apex angle, the value of termination resistor (R), and the heights of the feed (H_f) and the terminations (H_t). The length of the shorting wire (S) is determined by the apex angle and element length. The terminating resistors in Fig 1 are on the ground (earth's surface, H_t=0), which is a popular implementation because of its simplicity. This isn't a requirement, however, and as a general rule performance is improved by elevating the terminations.

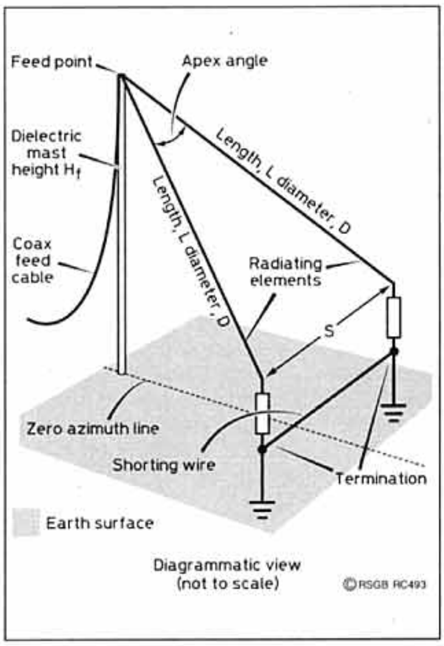

Fig 1: Typical sloping Vee installation.

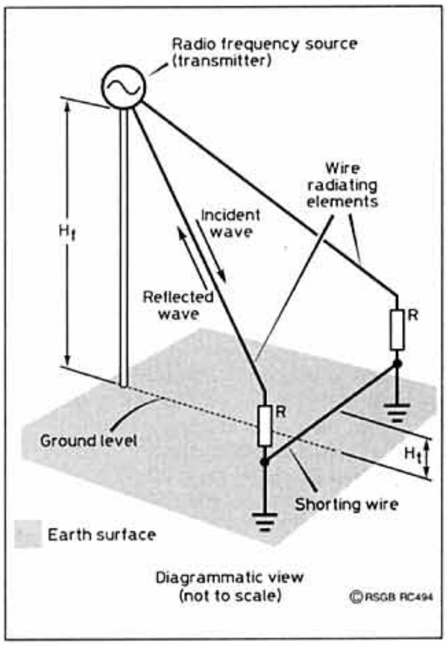

Fig 2: Sloping Vee schematic diagram.

One of the Vee's major advantages is simple installation. The antenna can be deployed almost anywhere, between trees, for example, or mounted on a building or other structure; the range of possibilities is limited only by your imagination. Most antennas don't provide the installation flexibility that the Vee does. About the only caveat is that, like any antennas, the Vee's performance is influenced by nearby metallic structures. If they're too close to the radiating elements, parasitic effects may become a problem.

ELECTRICAL CHARACTERISTICS

FOR MOST ANTENNAS, impedance bandwidth, gain, radiation efficiency, and radiation pattern are usually the electrical characteristics of greatest interest. Bandwidth and gain are frequently combined in a single figure of merit called the gain-bandwidth product (computed by literally multiplying these quantities). The term 'gain' strictly refers to directive gain, which measures only how the antenna distributes energy in space geometrically, not how much power is actually radiated. Because of this limitation, gain and radiation efficiency are almost always combined into a single performance measure called power gain (computed by multiplying the directive gain by the radiation efficiency).

In this article, bandwidth is defined as the range of frequencies where the VSWR is less than a specified threshold (typically 2.5:1 - see **Box 1** over page). Gain means power gain, not directive gain, and it is given in decibels relative to an isotropic radiator (dBi). Power gain relative to a dipole (dBd) is 2.15dB less (eg, 5dBi = 2.85dBd), because a free space half-wave dipole has a gain of 2.15dBi.

The radiation pattern of an antenna is simply a plot of its gain as a function of direction in space specified by two angles. The pattern is therefore a graphical representation of how the antenna distributes energy throughout space. Sloping Vee patterns are discussed in detail in the design examples that follow.

Still another measure of antenna performance is polarisation. Two antennas must be co-polarised (polarised in the same direction) in order to communicate; totally cross-polarised antennas cannot communicate. Polari-

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* *116 Stiles Road, Boylston, Mass, 01505-1506 USA.*

BOX ONE

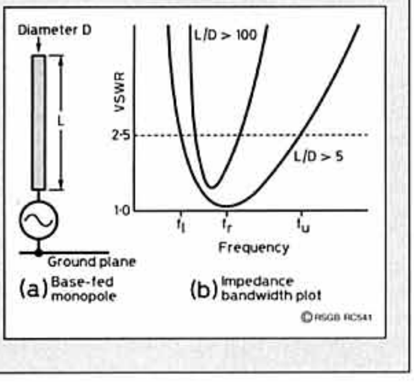
IMPEDANCE BANDWIDTH

IMPEDANCE BANDWIDTH is defined as the range of frequencies where an antenna meets a given input impedance specification. It's commonly referred to simply as the bandwidth, which is the convention adopted here. Bandwidth can be specified in terms of impedance values (resistance & reactance, or magnitude & phase), but most of the time, VSWR (voltage standing wave ratio) is used instead because the VSWR depends on the antenna's input impedance.

If an antenna is perfectly matched to its feed system (for example, a 50Ω resistive input impedance driven by a 50Ω coaxial cable), then the VSWR is 1:1. As the input impedance deviates more and more from the feed system impedance, the VSWR goes up as the mismatch gets worse. With increasing VSWR, the load absorbs less incident power and, at the same time, the transmitter output power begins to fall off. Eventually, when the VSWR is too high, the transmitter shuts down or overheats. Maximum allowable VSWR is usually set at 2.5:1 because modern transmitters can tolerate that level without serious adverse effects. But the threshold can be higher or lower than 2.5.

The bandwidth concept is best illustrated by an example. A base-fed monopole antenna is shown in **(a)** of the illustration below. It has length L and diameter D. The RF source is connected between its lower end and a large, highly conductive ground plane. A 'thin' monopole has a large L/D ratio; the element is very long compared to its diameter. A 'fat' monopole has a small L/D ratio; the radiating element diameter is a significant fraction of its length. The bandwidth of this antenna is highly dependent on the L/D ratio.

Monopole VSWR is plotted in **(b)**. The thin antenna (L/D > 100) has a narrow response curve in which its VSWR is below 2.5:1 only over a frequency range of about 15% of the frequency for minimum VSWR. This antenna's 'fractional bandwidth' is said to be 15%. By contrast, the fat monopole with L/D = 5 has a much broader response. Its VSWR is less than 2.5:1 over about 50% of the frequency for minimum VSWR; that is, $(f_u - f_l)/f_r = 0.5$. the fat monopole's fractional bandwidth is more than three times larger than its thin cousin's. These curves illustrate the concept of impedance bandwidth and also how electrically different even geometrically similar antennas can be.



(a) Base-fed monopole (b) Impedance bandwidth plot

sation is important on links that don't alter the transmitted polarisation (a line-of-sight microwave link, for example). But ionospheric channels can drastically alter transmitted polarisation, and, as a rule, antenna polarisation isn't a matter of great concern.

Nevertheless, the Sloping Vee offers an advantage over most other antennas because its radiating elements are inclined wires that transmit and respond to both horizontal and vertical electric fields. The degree of this inherent polarisation diversity depends on the actual wire inclination, which, of course, varies from antenna to antenna. On links where polarisation fading is expected to be significant, the antenna designer is well advised to consider Vees that transmit and respond to vertical and horizontal fields more or less equally in the range of take-off angles of interest.

A properly designed Vee is a travelling wave antenna (see **Box 2**). Unlike resonant (standing wave) structures, travelling wave antennas provide large operating bandwidths without tuners or broadbanding networks. The usual trade-off (there's always a trade-off) is that the radiating structure bandwidth is increased by sacrificing radiation efficiency. The terminating resistors in a Vee introduce a frequency-dependent I^2R loss (joule heating) that reduces the radiated power. But the bandwidth increase over a resonant system is dramatic. One of the antennas described below, for example, provides a 6:1 bandwidth ratio (10-60MHz) with a VSWR less than 1.75:1.

The Vee's power gain varies with frequency and also with ground electrical parameters (conductivity and dielectric constant). The gain can fall off very quickly at band edges, but mid-band gain can be moderate to high, depending on the design. For example, another one of the antennas discussed below has only 1.78dBi gain at its low frequency end (5MHz), but more than 8dBi gain between 15 and 30MHz. When very high gain is the primary requirement, and bandwidth and size are secondary, the Vee can provide spectacular performance. At 10MHz, for example, 16.5dBi gain is achieved by a Vee with the following parameters: 15 degree apex; 210 metre long, 0.32cm diameter elements; feed point at 33.75m and terminations at 37.5m over average ground.

The basic Sloping Vee design methodology is to change parameters iteratively until the structure meets minimum gain, pattern, and bandwidth requirements while at the same time accommodating siting constraints, if any. For example, the desired main lobe gain might be 10dBi for take-off angles between of 12 and 16° at all frequencies from 10 to 30MHz. A typical bandwidth requirement would be a VSWR of less than 2.5:1 over the same frequency range. And a typical siting requirement might be a feed point height less than 20 metres with the terminations on the ground. To meet these requirements, an initial configuration is assumed by assigning values to all design parameters. These values are then iteratively changed to modify the gain, main lobe take-off angle, and bandwidth until the design objectives are met.

TYPICAL VEE DESIGNS AND PERFORMANCE

APEX ANGLE

The first Vee parameter that should be specified is the apex angle. Once the other design parameters are fixed, there's only one apex angle that provides maximum antenna gain. Choosing the apex angle is therefore neither arbitrary nor simply a matter of convenience. The optimum (maximum gain) apex depends on two things, the operating frequency and radiating element length. By its very nature as a broadband antenna, the Vee's operating frequency varies, and there isn't one apex angle which is optimum for all frequencies. For a specific element length, the angle that's optimum at one frequency will not be optimum at another.

Choosing the apex angle is a matter of engineering judgement based upon design objectives and how antenna performance changes as the apex is changed. Plots of the optimum apex angle versus element length and frequency are shown in **Fig 3**. Fig 3(a) includes curves for three frequencies (5, 17.5 and 30MHz), while 3(b) includes curves for three element lengths (40, 80 and 120m). To illustrate how these plots are used, at 5MHz the optimum apex angle is approximately 79° with a 90m long radiating element. But at 20MHz, the optimum value is about 60° for 40m elements. The data show that, at a fixed frequency, the optimum angle gradually decreases as the radiating element gets longer. The same effect is seen for the frequency variation; for a fixed element length, the optimum apex decreases as the frequency goes up. But the variation in apex angle is greater with changing frequency than it is with changing element length.

Curves like those in Fig 3 are used to

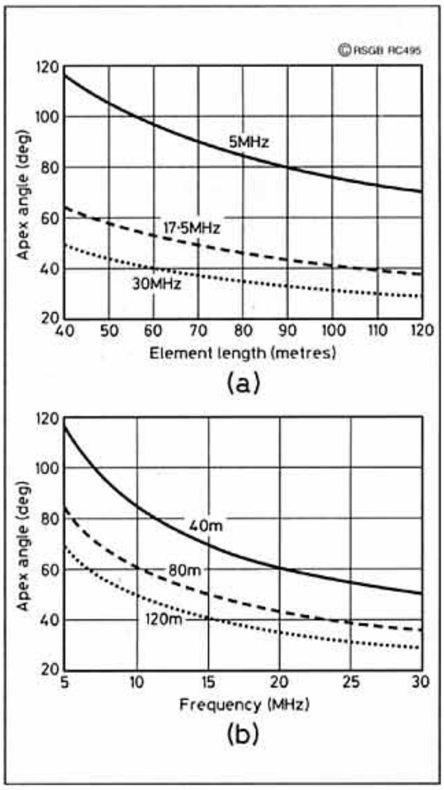


Fig 3: Optimum apex angle.

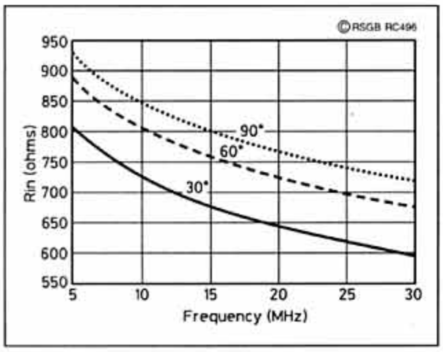


Fig 4: Sloping Vee input resistance.

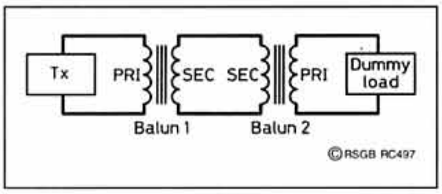


Fig 5: Balun back-to-back insertion loss test.

	Apex Angle (deg)		
F(MHz)	30	60	90
5.0	809	888	930
17.5	659	738	779
30.0	594	673	715

Table 1: Summary of resistance valves.

specify an initial apex angle, usually by doing an 'eyeball average' of the plots. For example, if long elements are acceptable, the designer might look at only the data for 120m elements. For that length, the optimum apex decreases from 70° at 5MHz to about 28° at 30MHz. If an 'average' apex angle with respect to frequency is chosen, a reasonable starting value is 40°. If performance above 15MHz were considered more important than across the entire band, then the initial apex should be reduced, say to 32°. This procedure illustrates how the optimum apex angle data would be used in the initial design step.

INPUT RESISTANCE

Professional antenna engineers think of the Vee as a '600Ω' antenna, which, as an engineering rule-of-thumb, probably isn't too bad an estimate. The problem is that it obscures what actually happens in the antenna. **Fig 4** shows the input resistance as a function of frequency for apex angles of 30, 60 and 90°. A glance reveals that the input resistance is anything but constant! It varies with apex angle, radiating element diameter (0.32cm in this case), and, of course, with operating frequency. Because the apex and element diameter are fixed in a specific Vee design, the frequency variation is what's important.

Table 1 summarises data from the plots. The table entries are input resistance (R_{in}) in ohms at 5, 17.5 and 30MHz. The table shows that the assumption of a 600Ω input resistance can be seriously in error. At the low end of the band, R_{in} is well above 600Ω for all three apex angles. This particular antenna is close to 600Ω only above 17.5MHz with the 30° apex. Average values of R_{in} with respect to frequency (using all points on the plots, not just the data in the table) are, respectively, 671, 750 and 792Ω at 30, 60 and 90° apexes.

R_{in} is important because it determines the required characteristics of the antenna coupling network. Most modern transmitters are designed for 50Ω non-reactive loads. If the load isn't a pure resistance of 50Ω, then a coupling or matching network is required. Another reason why the Vee requires a coupler is that it's a balanced radiating structure. Feeding a Sloping Vee from an unbalanced source (a 50Ω coaxial cable, for example) requires the use of a balun, which must also match R_{in} to the feed system's characteristic impedance.

The usual Sloping Vee feed is therefore a broadband RF balun whose impedance ratio (square of the turns ratio) is the average value of R_{in} divided by the coax cable characteristic impedance. For example, if the Vee in Fig 4 has a 60 degree apex and is fed with 50Ω coax, the required balun impedance ratio is 750/50 = 15 (average R_{in} of 750 divided by 50). The balun turns ratio is the square root of 15, or 3.87:1 (secondary-to-primary).

Most amateur radio books describe how to build good baluns, but a word of caution is in order. Never build just one balun. Instead, build two identical devices and test them for power handling and insertion loss using the back-to-back arrangement shown in **Fig 5**. If the transmitter has a 50Ω output, then a 50Ω dummy load must be used.

The baluns must be tested at full operating power and should be carefully monitored for any sign of overheating or breakdown. The insertion loss (power dissipated in the baluns) should be measured using an in-line wattmeter.

BOX TWO

STANDING WAVE AND TRAVELLING WAVE ANTENNAS

ANTENNAS ARE BROADLY classified as either standing wave (resonant) or travelling wave (non-resonant). Standing wave antennas are narrowband, while travelling wave systems are broadband. Resonant antennas behave like a mismatched transmission line and non-resonant antennas like a matched line.

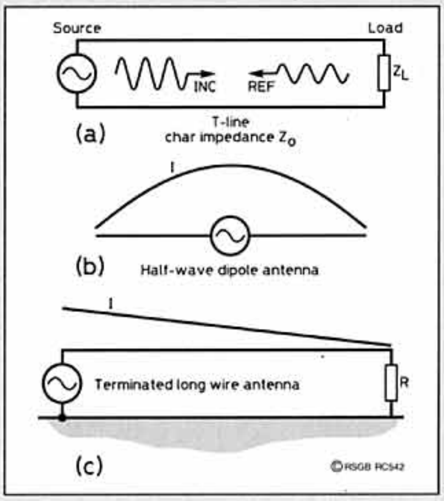
A transmission line of characteristic impedance (Z_o) connecting an AC source to a load (Z_L) is shown in (a) of the illustration below. It's assumed that the source and line are matched, which is usually the case (50Ω transmitters feeding 50Ω coaxial lines). Signals from the source propagate along the line toward the load. When the load and line are perfectly matched, all incident energy is absorbed by the load, and there is no reflected signal.

A perfect match requires that the load impedance Z_L be equal to the complex conjugate of Z_o. The conjugate match to Z_o=50-j12Ω, for example, is Z_L=50+j12Ω (just reverse the sign of the reactance). In a well designed line, reactance is not an issue because Z_o is purely resistive. The matched load is then also a pure resistance of equal value. For standard 50Ω coax cable, the perfect match is a 50Ω non-reactive load.

When Z_L and Z_o are mismatched, some of the energy incident on the load is reflected. The incident and reflected signals travel in opposite directions along the line and produce a standing wave pattern as they combine. this situation is analogous to the ripples formed on the surface of still pond when disturbances from a rock thrown into the centre combine with ripples reflected from the shore.

The signals on an antenna propagate from the feed point outward along the radiating structure. Reflected signals, which travel back along the structure toward the feed, are generated at every impedance discontinuity (the end of an element, for example). The antenna behaves like a mismatched T-line, with one major difference. It radiates energy into the surrounding space, but the T-line doesn't.

An example of a *resonant* or *standing wave* antenna is the half-wave, centre-fed dipole in (b). Signals from the source travel outward toward the ends of the elements. Because each end is electrically isolated, the current there must be zero. To meet this boundary condition, a reflected wave is generated which exactly cancels the incident signal at the end of the element. As the reflected wave travels back toward the source, it combines with the incident signal to produce a standing wave current distribution (I).



The current I is approximately sinusoidal, with its maximum at the feed point and falling to zero at the ends of the antenna. The half-wave dipole is resonant because signals of only one frequency produce a half-wave current distribution; all other frequencies produce a different one. Because the current distribution changes dramatically with frequency, the antenna input impedance changes just as dramatically. This behaviour is characteristic of standing wave antennas.

An example of a *non-resonant* or *travelling wave* antenna is the terminated long-wire in (c). Signals from the source propagate along the wire toward the end, which is terminated by a resistor (R). The current (I) decreases along the wire because energy is radiated away from the antenna and because of wire losses. Any remaining energy which is incident on the termination is absorbed by the resistor and converted to heat (I^2R loss).

By eliminating the impedance discontinuity produced by an unterminated element, the terminating resistor suppresses reflections and increases the operating bandwidth (at the expense of efficiency). Since only the incident wave propagates along the antenna, there is no standing wave to produce resonance effects. The electrical characteristics of an ideal non-resonant antenna are therefore independent of frequency, which is why the system exhibits a very wide bandwidth.

HF LINK GEOMETRY

Let's consider an HF link between Sheffield, UK and Chicago, Illinois, USA. The great circle distance between these cities is 6146km (3841 statute miles), and the bearing to Chicago from Sheffield is 296° east of north. If the link were between Sheffield and New York City instead, the distance drops to 5381km (3363 statute miles), and the bearing changes to 286°.

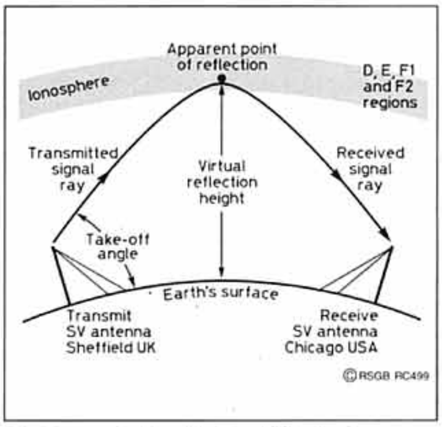


Fig 6: Ionospheric reflection of HF signals.

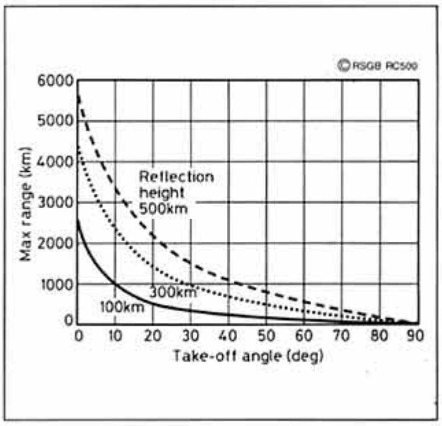


Fig 7: Communication range plot.

The normal HF propagation mode is illustrated in **Fig 6**. The transmitted signal is reflected from the D, E or F regions of the ionosphere. HF links can be single hop as shown, or, over very large distances, multiple hop. The ray path isn't actually made up of straight lines as shown. Rather it's a very complex shape determined by how the ionosphere's electron density profile bends the path of an electromagnetic wave. Nevertheless, no matter how complex the ray path actually is, an ionospheric radio link can be thought of as being made up of straight-line transmitted and received signal rays 'reflected' from a single 'virtual' point. The reflection occurs at a virtual reflection height that depends upon the propagation characteristics and the link geometry.

The geometry in Fig 6 determines the range of take-off angles needed to support a particular link. Communication is possible only if the transmit (Tx) and receive (Rx) antennas generate and respond to signals at the correct take-off angles. The relationship between take-off angle and Tx-Rx range is shown in the communication range plot of **Fig 7.** Maximum Tx-Rx range is plotted as a function of take-off angle for three different reflection heights (100, 300 and 500km). Of course, shallow angles (near the horizon) give the greatest range, while steep angles (nearly overhead) provide the shortest. These range curves have been computed for a '4/3 radius earth', which is the standard correction applied to take into account ionospheric refraction at HF.

As Fig 7 shows, the link to Chicago is too long for a single hop even with a 500km virtual reflection height. The maximum range (zero take-off) is about 5600km, which is less than the required distance of 6146km. Two hops are therefore required. At 500km virtual height, half the path is covered by signals at a take-off angle of about 11°. But the link can also be made with signals at 6° take-off using 300km reflections. Thus, for 2-hop F-region propagation between Sheffield and Chicago, the antenna should have maximum gain at take-off angles of 6 to 11°. The corresponding angles for a link to New York City are somewhat higher (7-15°) because the link is shorter.

This analysis shows how HF link geometry influences antenna design objectives. If a Sloping Vee is intended to support HF links from the UK into the eastern half of the US, then the range of significant take-off angles is between approximately 5 and 15°. The Vee should therefore be designed to produce maximum radiation (gain) at angles in that range.

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SEVERAL EXAMPLES OF Sloping Vee performance are discussed in this section, mostly in terms of radiation patterns. Before examining the radiation patterns, however, it's useful to review the geometry and concepts presented in **Fig 8.** Antenna characteristics are described in spherical polar co-ordinates defined with respect to a right-handed Cartesian (XYZ) co-ordinate system. The antenna is located at the origin, and the X-Y plane is earth's surface. The zenith is overhead in the direction of the +Z axis.

Directions in space are specified by two angles, azimuth and polar angle. The azimuth is measured counter-clockwise from the +X axis in the Z-Y plane (viewed from above). The polar angle is measured from the +Z axis as shown. A polar angle of zero corresponds to directly overhead, while 90° is at the horizon. The take-off angle is the complement of the polar angle. Zero take-off is in the direction of the horizon, while 90° take-off is overhead.

Because of the mixed polarisation from a Sloping Vee antenna, its electric field contains a horizontal component and a vertical component. These far field vectors are perpendicular to each other and to the wave vector, which points radially outward in the direction of propagation. The total radiated electric field is the vector sum of the horizontal and vertical fields; it's inclined at an angle determined by their relative magnitudes. Note that the vertical field is 'vertical' (in the sense of perpendicular to the X-Y plane) only when the take-off angle is zero. Directly above the antenna, the vertical field is actually horizontal!

The power flux radiated by an antenna in a specific direction (watts/square metre) is proportional to the square of the electric field strength divided by the impedance of free space (377Ω). Power gain is computed as the ratio of the flux actually produced by the antenna to the flux that would be produced by an ideal isotropic radiator with the same input power. The isotropic source is a fictitious antenna that radiates equally well in all directions.

For example, if a particular Vee produces a flux of 20 watts/sq m at a take-off angle of 10° and an azimuth of 5°, and if the isotropic flux for the same input power were 1 watt/sq m, then the Vee's power gain at 10° take-off, 5° azimuth, is 20. What this means is that the Vee produces 20 times more power per unit area in that direction than an isotropic source with the same input power. The power gain in dBi is given by the familiar expression 10og(20) = 13dBi.

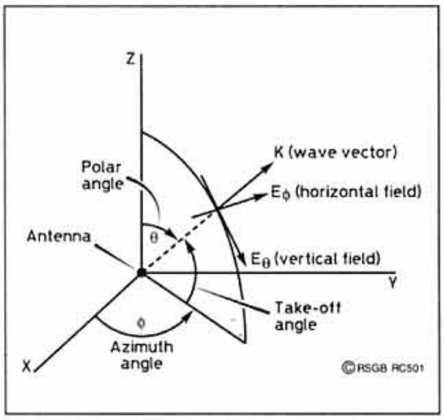

Fig 8: Electric fields radiated by the antenna.

5-30MHz HF Vee

The first antenna considered in detail is an HF design with the following parameters:

Apex Angle = 60°
Radiating Element Diameter = 0.32cm
Feed Point Height = 12 metres
Termination Height = 4 metres

This antenna's radiation patterns were computed for average ground (conductivity = 0.005 Siemens/m, dielectric constant = 8) at frequencies of 5, 7.5, 15, 22.5 and 30MHz for two radiating element lengths (40, 120m). All patterns are in the vertical plane at zero° azimuth (that is, the plane perpendicular to the earth's surface that bisects the angle formed by the radiating elements). The take-off angles run from zero (horizon) to 90° (Zenith). Plotted patterns appear in **Figs 9(a) - 9(e)**. Following standard practice, linear scales are used because they provide better resolution of fine detail than do polar plots.

Pattern features of particular interest include the main lobe gain and take-off angle, and first sidelobe level and angle, which are summarised in **Table 2**. In the table, L is the radiating element length, G_{max} is the main lobe maximum gain, and 1st SL (dBi) is the first sidelobe level. Angle is the take-off angle at which the corresponding gain is achieved.

The results show that this design (which has not been optimised) provides moderate gain over most of the HF band. With the long radiating element (120m), the Vee's gain increases from 1.8dBi at 5MHz to 10.6dBi at 22.5MHz, followed by a decrease to 8.6dBi at 30MHz. The corresponding values for the

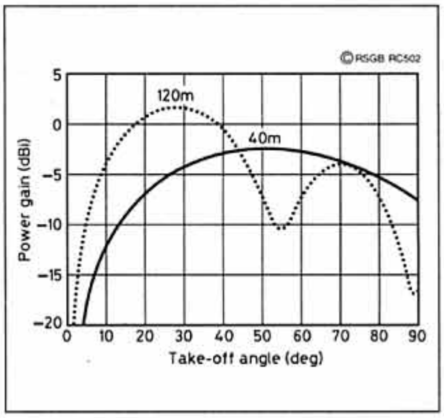

Fig 9(a): Sloping Vee pattern at 5 MHz.

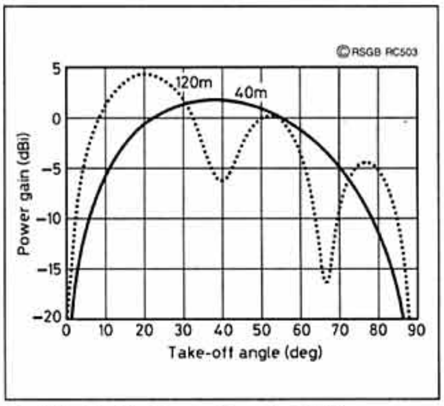

Fig 9(b): Sloping Vee pattern at 7.5 MHz.

L (m)	Gmax (dBi)	Angle (deg)	1st SL (dBi)	Angle (deg)
Frequency = 5.0MHz				
40	-2.5	51	-	-
120	1.8	28	-4.0	70
Frequency = 7.5MHz				
40	1.9	38	-	-
120	4.4	21	0.3	52
Frequency = 15.0MHz				
40	8.1	22	-3.8	57
120	7.0	28	-0.4	45
Frequency = 22.5MHz				
40	10.3	15	3.3	40
120	10.6	15	2.5	31
Frequency = 30.0MHz				
40	10.1	11	6.7	30
120	8.6	8	6.2	21

Table 2: Pattern features of interest; 5-30MHz Vee.

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* *116 Stiles Road, Boylston, Mass, 01505-1506 USA.*

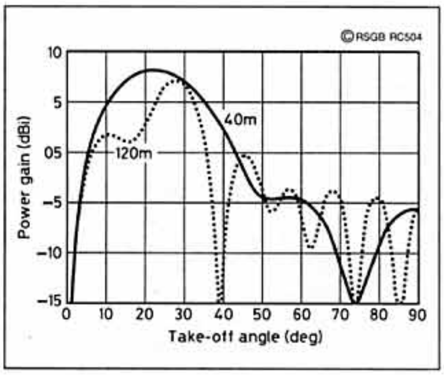

Fig 9(c): Sloping Vee pattern at 15 MHz.

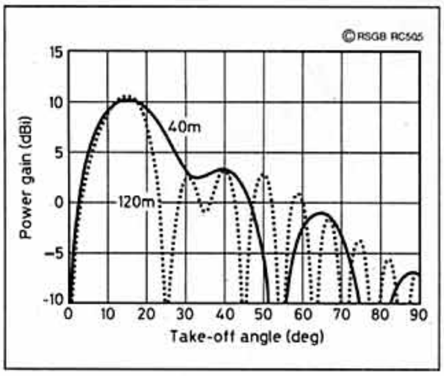

Fig 9(d): Sloping Vee pattern at 22.5 MHz.

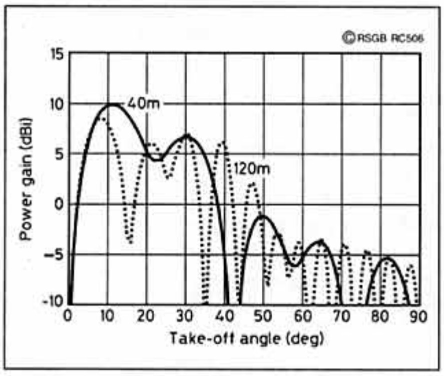

Fig 9(e): Sloping Vee pattern at 30 MHz.

short (40m element are -2.5, 10.3 and 10.1dBi. The short element design could be used in a space-limited installation, but the larger one provides better low band performance.

With the long radiating element, the range of take-off angles for maximum gain is 28° at 5MHz to 8° at 30MHz. For the short element, the range is 51° to 11°. At the low end of the band, the short element isn't long enough to break up the pattern (40m compared to 60m wavelength at 5MHz). Radiation is distributed in a single, smooth main lobe extending essentially from horizon to zenith. The long element, by contrast, shows the scalloped pattern characteristic of radiators that are longer than the wavelength.

48-56MHz VHF Vee

The HF Vee described above covers at least a 6:1 frequency range. If a smaller range is acceptable, especially for single band or closely spaced multi-band operation, then the antenna can be designed for higher gain. The Vee described in this section covers the US 6-metre amateur radio band (50-54MHz) with high gain. Its design parameters are as follows:

Apex Angle = 15°

Radiating Element Diameter = 0.32cm

Feed Point Height = 6 metres

Termination Height = 8 metres

This antenna, unlike the HF Vee, has the terminations higher than the feed point. As a general rule, this arrangement provides better performance. For practical reasons, however, many Vees are built with the terminations lower than the feed, frequently right on the ground.

The 6-metre Vee's input resistance is 455, 446, and 437Ω, respectively, at 48, 52 and 56MHz. Using an average value of 446Ω, each radiating element should be terminated by a 223Ω non-inductive resistor (in practice, 200 or 250Ω is close enough). Since the computed input resistance varies only 4% between 48 and 56MHz, this design should provide essentially flat VSWR from 50-54MHz.

Radiation patterns were computed at 48, 52 and 56MHz for three radiating element lengths (20, 40 and 60 metres); they are plotted in **Fig 10(a) - (c)**. Like the HF patterns, these radiation patterns are in the vertical plane bisecting the elements (zero azimuth angle). **Table 3** summarises some of the important performance parameters. 3dB BW is the approximate main lobe beamwidth between -3dB points (3dB down from the maximum gain). 1st SL (dB//Gmax) is the first sidelobe level relative to the maximum gain ('dB down' from the main lobe).

It is apparent that this simple antenna provides exceptionally good gain performance throughout the 6-metre band. The gain increases from 16.3 to 18dBi between 48 and 56MHz using the longest (60m) radiating element. Even the shortest element (20m) provides moderate gain (7.7-9.3dBi). For all element lengths, maximum gain occurs at take-off angles between 9 and 12°, which are suitable for long range links. As this example shows, the physical size of a high gain Vee can be large. But the dimensions become less imposing when they're compared to the size of a yagi providing the same gain. Of course, at higher frequencies, especially high VHF and UHF, the shorter wavelengths result in much smaller designs.

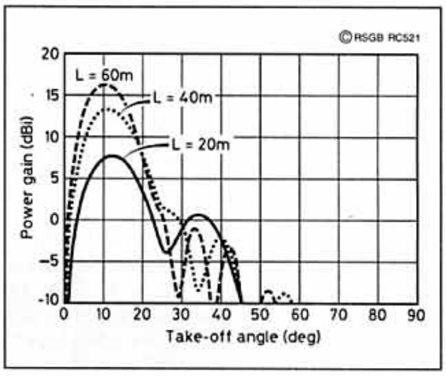

Fig 10(a): Sloping Vee pattern at 48MHz.

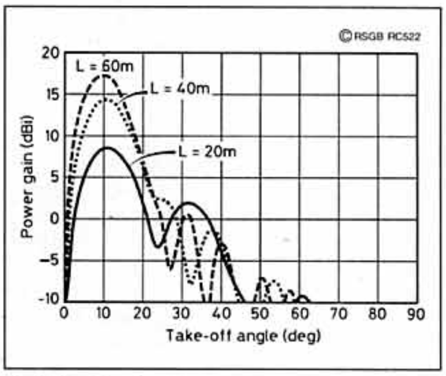

Fig 10(b): Sloping Vee pattern at 52MHz.

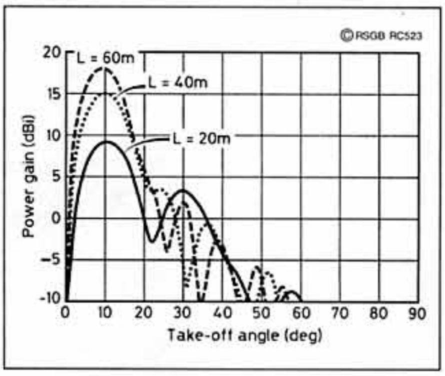

Fig 10(c): Sloping Vee pattern at 56MHz.

10-60MHz HF/VHF Vee

As a final example of Vee performance, the measured VSWR data for an upper HF/lower VHF Vee on average ground are presented. The antenna was designed to provide moderate gain (4-8dBi) from 20 to 60MHz with a small footprint. It turned out that the antenna was actually usable down to below 7MHz. Its design parameters are as follows:

Apex Angle = 70°

Radiating Element Length = 20m

Radiating Element Diameter = 0.32cm

Feed Point Height = 6m

Termination Height = 0m

The radiating elements were terminated with off-the-shelf 100 watt, 300Ω non-inductive power film resistors (even though the input resistance was closer to 700Ω than to 600). The antenna was used continuously at 800W input power without problems. However, as a rule of thumb, the resistors should be rated to handle 25% of the RF input power. Under some circumstances, up to 50% of the input power may be dissipated in the resistors.

The antenna's VSWR is plotted in **Fig 11**.

L (m)	Gmax (dBi)	Angle (deg)	3dB BW (deg)	1st SL (dBi)	1st SL (dB//Gmax)
			Frequency = 48MHz		
20	7.7	12	12.6	0.5	7.2
40	13.3	11	12.0	-2.3	15.6
60	16.3	11	10.6	-1.1	17.4
			Frequency = 52MHz		
20	8.5	11	11.9	1.9	6.6
40	14.2	10	11.0	-1.5	15.7
60	17.2	10	9.9	0.3	16.9
			Frequency = 56MHz		
20	9.3	10	11.0	3.3	6.0
40	15.0	10	10.4	-0.9	15.9
60	18.0	9	9.5	1.8	16.2

Table 3: Pattern features of interest; 48-56MHz Vee.

It was measured at the input to 150ft of low-loss 50Ω coaxial feeding the antenna and at the balun. At the cable input, the VSWR is below 1.5:1 at most frequencies from 10 and 60MHz. The average VSWR at the coax input was 1.41:1 and 1.73:1 at the balun. This antenna illustrates how good a Vee's VSWR performance can be over a wide frequency range.

It's common practice to define an antenna's impedance bandwidth relative to a VSWR threshold of 2.5:1 (see Box 1 in Part 1). Although the threshold should be set by the characteristics of the specific Tx being used, a value of 2.5:1 is representative for modern equipment. The VSWR for the HF/VHF Vee is well below 2.5:1, and it's low enough that no antenna tuner or matching network is required. This Vee can be loaded directly at any frequency between 10 and 60MHz (and, in fact, beyond).

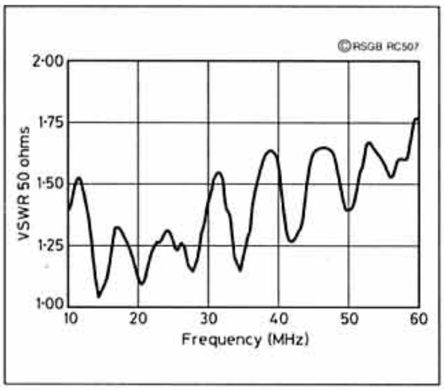

Fig 11: Sloping Vee, measured VSWR.

SOURCES OF MATERIALS

IF YOU WANT to experiment with Sloping Vees, you may wish to contact the following US companies for information. A Sloping Vee computer modelling program is essential to designing a good antenna. It's the only way to investigate performance trade-offs as various antenna or ground parameters are changed.

The radiation patterns, apex angle plots and input resistance plots were computed using PC (IBM-compatible) software supplied by Phadean Engineering Co Inc, PO Box 611, Shrewsbury, MA 01545-8611. Phadean provides inexpensive ($10-$30) antenna design software.

Non-inductive film power resistors for terminating your Vee are available from Power Film Systems Inc, Yellville, AR 72687. PFS's standard values should cover most applications, but custom devices are available at extra cost if required. Toroidal and cylindrical ferrite cores for winding baluns are available from Radio Kit Inc, PO Box 973, Pelham, NH 03076 (be sure to run back-to-back tests!)

7 x 9 stranded phosphor-bronze cable is an excellent wire for the radiating elements. It's especially useful if the Vee will be installed and removed frequently (doesn't kink or tangle). It's available from Astro Industries Inc, Dayton, OH 43432. If a non-metallic mast is desired or required, a very strong, non-bending, thick-wall fibreglass tubing called EXTREN 500 is distributed by J T Ryerson Co, PO Box 1111, Boston, MA 02103. Since the phosphor-bronze wire and EXTREN are quite expensive (about $2 and $4 per foot, respectively), most experimenters won't want to spend that much. This information is being provided for completeness. The Vee's electrical performance is the same whether an exotic stranded cable or a plain single-conductor wire is used. The main difference is convenience. As far as masts go, 'masts of opportunity' (trees) provide the same results as fancy dielectric ones, with somewhat less convenience perhaps, but almost certainly more fun!

CONCLUSION

THIS ARTICLE HAS discussed Sloping Vee design and performance. The Vee is inexpensive, mechanically and electrically simple, easily transported and installed, and, most importantly, it provides excellent gain-bandwidth performance. The Vee also provides the added bonus of inherent polarisation diversity because the radiating elements are inclined wires.

Sloping Vee performance has been illustrated by several design examples. Just about any performance characteristic can be changed by suitably modifying the antenna design. The Vee can provide a balance between gain, take-off angle, and bandwidth, or it can be designed to optimise a single performance parameter. The examples have illustrated various design approaches that achieve different balances. ♦

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Notes
SF = State Frequency or Band

Author	Date	Kit	Contents	Price	Notes
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Technical Update

HF/VHF VEE BEAM DESIGN AND PERFORMANCE, MAR 95

WE HAVE RECEIVED the following letter from P L Stride, G2BUY, regarding the article on HF/VHF Vee Beam Design and Performance by Richard A Formato, K1POO.

"The HF Link Geometry section of this article contains a number of obvious misconceptions.

"Fig 6 shows all the ionospheric layers at a common altitude rather than at the correct levels of about 60km for D, 120km for E, 250km for F1 and 300/500km for F2. It is also inferred that the D layer contributes to the returning signal whereas it only introduces attenuation. In practice, only the F2 layer is important in long distance paths above about 2000km.

"The text and Fig 7 refer to the use of the '4/3 radius earth'. This concept was introduced to account for the increased ground range resulting from *atmospheric* refraction of higher frequency HF, VHF and microwave signals. It is not applicable to paths above about 1km and has no relevance whatever to ionospheric propagation. Amended figures for Chicago and New York are:-

Layer Height 500km		
Distance, km	**Hops**	**Take-off Angle**
6146	2	10.4°
5381	2	13.6°

Layer Height 300 km		
Distance, km	**Hops**	**Take-off Angle**
6146	2	3.8°
	3	11.3°
5381	2	6.2°
	3	14.0°

"The errors are only significant at low take-off angles.

"It would also have been interesting to know something of the origins of the computer programme on which the article is based and of any experimental verification."

The author replied:

"The purpose of Fig 6 is to illustrate the concept of virtual height and its importance in determining the range of take-off angles needed to support a particular link. Fig 6 is not intended to imply that the usual ionospheric layer model places all the layers at one height. Quite to the contrary, the virtual reflection height typically varies between 100 and 500km, which is why Fig 7 plots curves for virtual heights in this range. A good discussion of this topic is available in [1], Section 17.04.

"The 4/3 earth correction applies only to groundwave propagation, not to ionospheric paths. The communicated range plot in Fig 7. should therefore be replaced with the enclosed plot [shown on the right - *Ed*] which is computed for an actual mean spherical earth radius of 6371km. Reference [1] Section 16.07 is a good source of information for readers interested in atmospheric refraction effects.

"The antenna patterns were computed on a PC using a program that implements Dr M T Ma's sloping vee model described in [2], Section 6.1. Impedance bandwidth was experimentally verified on several antennas, and the measured VSWR results in Fig 11 are typical. Detailed pattern measurements have not been made. Several antennas were built and operated very successfully on links in Greenland, between Greenland and the USA, and between Christchurch, NZ, and Antarctica.

"[1] *Electromagnetic Waves and Radiating Systems*, Second Edition, Edward C Jordan and Keith G Balmain, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1968.

"[2] *Theory and Application of Antenna Arrays*, M T Ma, Wiley-Interscience, John Wiley & Sons, New York, 1974."

LF MOBILE ANTENNA DESIGN, FEB 95

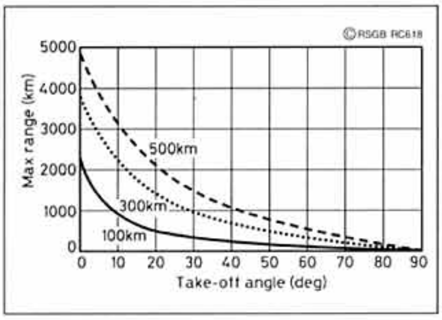
WE HAVE ALSO received a letter from P L Stride, G2BUY, regarding the article on LF mobile antenna design, R Bearne, G4DUA

"On the first page in discussing radiation resistance, the author first quotes a formula then continues with two examples which are incorrect. The correct figures are 0.0658 and 0.148 respectively. However, the correct values do subsequently appear in Table 3.

"In discussing antenna capacitance the author quotes a formula which is plainly incorrect as it fails to pass the simple test of Dimensional Analysis. It is clear that the numerator should contain the variable h representing the antenna length. Comparison with similar formulae in related fields indicates that the expression in square brackets should appear as a denominator not as a numerator. With these changes the expression comes close to the right answers but still does not reproduce the figures given in Table 3. A minor adjustment to the numerical constant does reproduce the Table 3 figures. The corrected formula then reads:

"$C_a = 2 \pi E_o h / (\ln(h/a)-1.7)$

"This is in reasonable agreement with the formula given in Terman's *Radio Engineers Handbook* which I believe to be essentially correct.



"In the discussion on skin effect the variable omega is said to represent frequency in radians, this is incorrect it should read radians per second.

"In the discussion on maximising coil Q the author correctly quotes Butterworth's criterion of. Coil Diameter = 8/15 x coil length.

"The author then misinterprets this as '2:1 diameter to length ratio' whereas it should be interpreted as 2:1 length to diameter ratio! ie Butterworth is telling us that the coil should ideally be longer than it is wide - a fact which is generally recognised by those who have experience in this field. This is plainly not a simple slip as the subsequent coil design is based on this incorrect premise where the coil diameter is 75mm and the length is 40mm.

"There is a presentational error in Table 3 in that the first two columns have become conjoined and therefore read as nonsense. The correct presentation is as follows:

Antenna Length	Radiation Resistance
0.5	4.11E-03
1	1.64E-02
1.5	3.70E-02
2	6.58E-02
2.5	1.03E-01
3	1.48E-01

"In this table in order to calculate the antenna efficiency a figure has been assumed for earth loss resistance but its value to has not been declared. Investigation reveals this assumed figure to be 5 ohms - about half the figure which the author ascribes to his system later. The remaining figures in Table 3 appear to be correct with the exception of the relative gain figures which I am unable to reconcile with the associated efficiencies. For example taking the reference as 0.5m with a coil Q of 200 for which the efficiency is 0.01 compared with a 1m antenna of efficiency of 0.04 implies a power gain of 4 times corresponding to 6dB, yet the table gives a figure 8.07dB! Maybe there is a hidden rounding up error in the reference figure in the spreadsheet program which accounts for this discrepancy. This also impacts upon the graph shown in Fig 2.

"In the penultimate paragraph the author claims his coil measured 380mH (millihenries) but this should be 380 microhenries. This is significantly greater than the calculated value which appears in Table 3 as 318 microhenries. [This was not the author's fault, see note below-*Ed]*

"On a philosophical note, although the realisation of high Q is an important parameter in antenna efficiency which cannot be denied I believe another important parameter is low self capacitance associated with the loading coil since this acts to divert current from the whip radiator. This may account for why the very long coils favoured by the commercial manufacturers have proved to be so successful.

"The author makes a case for the use of Litz wire (or bunched conductors as it is now called) to obtain high Q and this reminds me

CONTINUED ON PAGE 80